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scribed, that is, I press this strip of glass slightly on the middle of the thigh on one side, and at the same time the extremities of the two woollen cords come to rest on the cushions. The movements of the needle are observed through a telescope (lunette). I have repeated this experiment thirty or forty times. Sometimes, and this case is the most frequent, the first deviation produced by the muscle in repose is directed in the same sense as that of the current of the gastrocnemius; sometimes the current is null, or almost null; sometimes, and this case is the most rare, the deviation is in a contrary direction, and this occurs most frequently in operating on the hinder portion of the thigh.

In all these experiments, the moment that the thigh begins to contract, the needle moves in a constant direction; the deviation which intervenes is greater or less according to the force of the contraction, and indicates constantly a descending discharge or current of extremely short duration, which traverses the thigh in the direction of the ramification of the nerves, and in a contrary direction to the current of the gastrocnemius.

II. "An Inquiry into the Muscular Movements resulting from the action of a Galvanic Current upon Nerve." By CHARLES BLAND RADCLIFFE, M.D., F.R.C.P., Physician to the Westminster Hospital. Communicated by Dr. SHARPEY, Sec. R.S. Received February 2, 1860.

(Abstract.)

In a lecture delivered about two years ago*, in which he treats among other things of the muscular movements resulting from the action of a galvanic current upon a motor or mixed nerve, Professor Claude Bernard says that some of the more important of these movements have been overlooked, and he quotes an account of some investigations by Dr. Rousseau of Vezy, which do away with certain very perplexing variations in the order of these movements.

The movements resulting from the action of a galvanic current upon nerve are usually divided into the three periods of double, alternate, and single contraction which are set down in the following Table :—

* *Leçons sur la Physiologie et Pathologie du système nerveux.* Tome i. Leçon 10. Paris, 1858.

TABLE I.—*The Nerve divided and lifted up at its end.*

	Direct Current.		Inverse Current.	
	Beginning.	End.	Beginning.	End.
Period of double contraction . .	Strong contraction.	Contraction.	Contraction.	Contraction.
Period of alternate contraction . .	Contraction.	0	0	Contraction.
Period of single contraction . .	Contraction.	0	0	0
Apparent irregularity—"Voltaic alternatives."				

Professor Bernard proposes to place another period before the first of these—a period corresponding to the normal unexhausted and undisturbed state of nerve, and characterized by contraction at the beginning of the two currents, direct as well as inverse.

The investigations of Dr. Rousseau show how it is that the order of these contractions is altered by certain changes in the arrangement of the nerve acted upon by the current. If *the nerve acted upon be divided and lifted up at its end*, so as to break the circuit of the *derived current**, the order of contraction is that which is put down in the preceding Table; if *the nerve acted upon be raised in a loop* (either without dividing it, or, after dividing it, by dropping down the end), so as not to break the circuit of the derived current, the order of contraction is that which is represented in the following Table:—

TABLE II.—*The Nerve in a loop.*

	Direct Current.		Inverse Current.	
	Beginning.	End.	Beginning.	End.
Period of double contraction .	Strong contraction.	Contraction.	Strong contraction.	Contraction.
	Contraction.	Contraction.	Strong contraction.	Contraction.
Period of alternate contraction . .	0	Contraction.	Contraction.	0
Period of single contraction . .	0	0	Contraction.	0
Apparent irregularities—"Voltaic alternatives."				

* Figures 3 & 4 on page 354 may serve to illustrate all that need be said respecting *the derived current*. In figure 3, the sciatic nerve of a frog's leg is

Now Dr. Rousseau shows that the order of contraction set down in the second Table is due to the action of this *derived current*. He shows, also, that by excluding the derived current (which he does by means of an ingenious triple arrangement of poles called the “rhéophore bifurqué”), the order of contraction becomes one and the same in the case where the nerve is divided and lifted up at its end, and in the case where the nerve is arranged in a loop, the order being that which is set down in the first Table.

On inquiring into these matters experimentally, the author finds reason to believe that Professor Bernard has wandered into some degree of error, and that the path of inquiry opened out by Dr. Rousseau is not only a right path, so far as its discoverer has traced it out, but that it leads to the explanation of some very curious alternating movements which have not hitherto been described. He has been led, also, to form certain conjectures respecting the *modus operandi* of electricity in muscular motion which he trusts may serve to simplify this very difficult and complex subject.

1. When nerve is in its normal, unexhausted, undivided state, there is, as Professor Bernard points out, contraction at the beginning of both currents, inverse as well as direct, and at the beginning only, *if a feeble current be used*. This, for example, will be the result of the application of the feeble current produced by partially moistening the small galvanic forceps of Bernard with saliva. But it is also a fact, that a stronger current—the current for example of a Pulvermacher’s chain of ordinary length moistened with vinegar—will produce contraction at the end as well as at the beginning of both currents (as in the period of double contraction), if applied to a nerve similarly circumstanced. Nay, it is a fact, that the feeble current of the forceps will give contraction at the beginning of both

arranged *in a loop* across the poles P N of a galvanic apparatus; the *primitive current*, indicated by the black arrow, passes by the shortest route from the positive pole P to the negative pole N; the *derived current*, indicated by the dotted arrows, passes by the longest route between these poles, and as it also proceeds from the positive pole P to the negative pole N, it passes in the contrary direction to that of the primitive current. In fig. 4, the sciatic nerve is divided between P and the thigh, as is meant where the nerve is spoken of as *divided and lifted up at its end*; and being divided, the only current passing is the primitive current; for the circuit of the derived current being broken, there can be no derived current in this case.

currents, and at this time only, *after* the stronger current of the chain has produced contractions at the end as well as at the beginning of both currents, and that we may produce alternately again and again the contraction confined to the beginning, and a contraction occurring at the end as well as at the beginning, of the currents, by applying alternately the feeble current of the forceps and the stronger current of the chain. The author finds, also, that the feeble current of the forceps will produce contraction at its end as well as at its beginning, if the nerve be raised and placed as a loop across the points of the forceps; and not only so, but that the same current will produce contraction only at its beginning, if it be applied after slipping away the points of the forceps, and so allowing the nerve to fall back upon the muscles. Hence the single contraction at the beginning of a *feeble* inverse or direct current, and not at the end, instead of indicating, as Professor Bernard supposes, the normal state of undisturbed and unexhausted irritability in the nerve, must only be looked upon as the result of the action of a feeble current under particular circumstances. In a word, the fact is one which reflects the strength of the current rather than the condition of the nerve.

2. The curious alternating movements, which do not appear to have been described hitherto, and which may be explained by means of the key which Dr. Rousseau has put into our hands, are best seen when the current is made to act upon the lumbar nerves of one side, but they are also seen in the case where a loop of sciatic nerve is acted upon.

Take the back, loins, and hind limbs of a frog with the lumbar nerves properly exposed, raise the nerves on one side into a loop without dividing them, place them over the platinum poles of a galvanic apparatus (a Pulvermacher's chain of ordinary length), and pass the current. On doing this, as might be expected, there is in the first instance, contraction in the limb to which the nerves acted upon belong, *but this contraction is slight and transient when compared with the contraction which is set up in the opposite limb, the nerves of which are not acted upon.* In this opposite limb, indeed, the contraction is sure to be both strong and tetanic. A little later (and it is to the phenomena of this stage that the author wishes to direct attention), and the results are as follows:—With the *inverse*

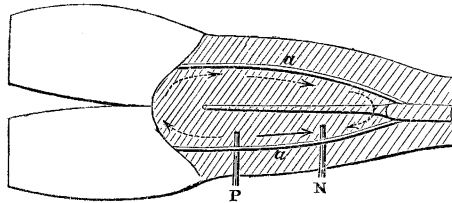
primitive current there is contraction in the leg belonging to the same side when the current begins to pass, and contraction in the leg belonging to the opposite side when it ceases to pass; with the *direct primitive current* this order of contraction in the two legs is reversed.

In bringing about these curious alternations, the action of a *derived current* is obviously concerned; for on excluding this current by means of Dr. Rousseau's rhéophore bifurqué, they come to an end, and the movements resulting from the action of the current are confined to the leg, the nerves of which are directly acted upon. It is evident, also, that a derived current is what is wanting to produce the contraction in the limb belonging to the opposite side; for after breaking the circuit of the derived current by dividing the lumbar nerves where they emerge from the spine, and separating the divided ends, and after then completing the circuit by dropping down the end of the divided nerve, or by bridging over the gap by a piece of wet string or paper, by a strip of the animal's skin, by a piece of wire, or by any other conductor, it matters not what, the contractions occur alternately in the two legs just as they did before the nerve was divided. Nay, it may be argued from the following experiment, that reflex nervous action has nothing to do in producing these alternations. Divide the lumbar nerves on one side, not where they emerge from the spine, but where they pass into the thigh; raise the divided end of the nerve, and place it across the poles of the galvanic apparatus. In this case the circuit of the derived current is broken, and the action of this current is therefore put out of the question. In this case, the nerve acted upon by the current is still in connexion with the spinal cord, and through the cord and the nerves proceeding from this cord, with the limb on the opposite side; and hence it might be supposed that the current might irritate the cord, and so provoke contraction in the limb on the opposite side. But the simple fact is, that the current may be passed inversely or directly without producing contraction anywhere, except now and then a few flickers in the muscular fibres in the lumbar region of the side corresponding to that of the nerve operated upon. The simple fact, indeed, appears to show that reflex nervous action can have nothing to do with the contractions in the limb belonging to the opposite side, which contractions are produced by the action of the

galvanic current on one set of lumbar nerves; and, certainly, with the key furnished by Dr. Rousseau, reflex nervous action is not required to explain the phenomenon.

The following diagram will give the case in which the lumbar nerves on one side are acted upon by the *inverse primitive current*, *a a* being the lumbar nerves, P N the poles of the galvanic apparatus, the black arrow the primitive current, the dotted arrows the derived current. The results, as seen in contraction in the limb belonging to the same side, or in that belonging to the opposite side, are seen in the Table below the figure. The case is plain.

Fig. 1.



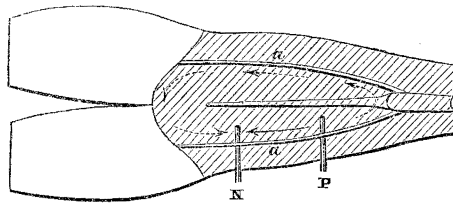
	The Inverse Current.	
	Beginning.	End.
On the same side . . .	Contraction.	0
On the opposite side . .	0	Contraction.

On the side acted upon by the inverse primitive current, the portion of nerve nearest to the muscles supplied by the nerve (the muscles of the leg) is traversed, not by the inverse primitive current, but by a *direct* derived current; and hence we should expect to find in the leg on this side (for at the time of these alternate contractions the nerve is in the state in which the current produces contraction alternately at the beginning of the direct current and at the end of the inverse current) the effects of a direct current—contraction at the beginning of the current. We should expect to find this; for of two currents acting upon the same nerve, it is the one nearest to the muscles supplied by the nerve which acts upon these muscles. In the limb on the opposite side we should expect, on the contrary, the effects of an inverse current—contraction at the end of

the current, for the lumbar nerves on this side are traversed by an *inverse* derived current; and this, as the Table shows, is actually the case.

A similar diagram and table will show that the results of passing a *direct primitive current* through a portion of the lumbar nerves on one side are in accordance with the same law. In this case, as in the other, the acting current on both sides is the derived current. On the side acted upon by the direct primitive current, the acting derived current (acting because nearest to the muscles supplied by the nerve) is *inverse*; and therefore the limb on this side ought to contract at the end of the current. On the opposite side, the course of the derived current is *direct*, and therefore the limb on that side ought to contract when the current begins to pass: and so it is.

Fig. 2.



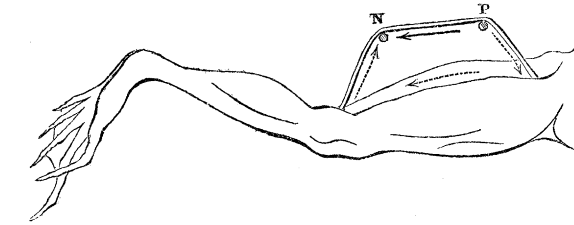
	The Direct Current.	
	Beginning.	End.
On the same side . . .	0	Contraction.
On the opposite side . .	Contraction.	0

The results of the action of a galvanic current upon a loop of sciatic nerve are, after a time, analogous to those which have just been mentioned. At first, the contraction attending upon the beginning and ending of both currents affects the whole limb; after a time, the leg and thigh contract alternately, in an order which changes with the direction of the current.

Let the following diagram and table represent the case in which a loop of sciatic nerve is acted upon by the *direct primitive current*, *a* being the nerve, P N the poles of the galvanic apparatus, the black arrow the primitive current, the dotted arrows the derived current; and it will be seen that the portion of nerve between the negative

pole and the leg is acted upon by an *inverse* derived current, and that the thigh is traversed by a *direct* derived current. Thus—

Fig. 3.

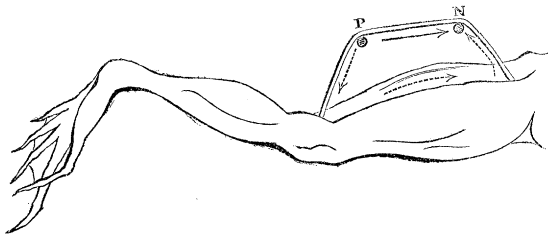


	The Direct Current.	
	Beginning.	End.
Thigh	Contraction.	0
Leg	0	Contraction.

Hence there ought to be, as there is in fact, and as the Table shows, contraction in the thigh when the current begins to pass, and in the leg when the current ceases to pass.

A similar diagram and table will give the case in which a loop of sciatic nerve is acted upon by the *inverse primitive current*, and show at a glance that the leg ought to contract at the beginning of the current, because the current, acting upon the portion of nerve nearest

Fig. 4.



	The Inverse Current.	
	Beginning.	End.
Thigh	0	0
Leg	Contraction.	0

to the leg, is *direct* derived current. The diagram will also seem to show that the thigh ought to contract at the end of the current, for the thigh is traversed by *inverse* derived current. In fact, however, the thigh does not contract either at the beginning or at the end of the current; and this perhaps is not to be wondered at; for the author finds that contraction attends upon the beginning of a *direct* current of a given strength for some time after it has ceased to attend upon the end of an *inverse* current of the same strength.

3. The *modus operandi* of galvanism upon a motor or mixed nerve is a subject beset with difficulties; but some of these difficulties do not appear to be altogether insurmountable.

(a) In looking at the movements belonging to the first period—*that of double contraction* (*vide* Table I.)—it is not difficult to find a reason which will in some degree explain how it is that contraction is confined to the beginning and end of the current. It is not difficult to see that the beginning and ending of the galvanic current in the nerve may involve certain changes in the strength of the nerve-current, and that these changes may in their turn give rise to momentary induced currents in the nerve and in the neighbourhood; for such momentary currents are induced, not only when a current begins to pass and when it ceases to pass, but also at the moments when it undergoes any change of strength. It is not difficult to see, also, that the muscular fibres to which the nerve is distributed may be the seat of some of the secondary currents thus induced, and that these fibres may be thrown into contraction by these currents. Nor is it difficult to see—if the contraction be thus connected with the induced currents—that there will be no contraction in the interval between the beginning and ending of the inducing galvanic current; for if the inducing current exhibits no variation in strength, there is no secondary current induced in this interval.

(b) It is, perhaps, too much to expect at present a full explanation of *the second period of contraction*—of that period, that is, in which the contraction alternates at the beginning of the direct and at the end of the inverse current; but the author is disposed to think that a partial answer may be found in the collation of the three facts which follow.

The first fact is this—that the direction of the nerve-current in the sciatic and lumbar nerves of a frog (except in those last moments of

all in which the action of the galvanic current upon the nerve gives rise to the "voltaic alternatives") is *inverse*. In these last moments the nerve-current in these nerves may be sometimes direct, sometimes inverse, and this change of direction may take place more than once; but except in these last moments, the author finds the direction of the nerve-current to be invariably inverse.

Fig. 5.



The second fact is furnished by Professor du Bois-Reymond in an experiment in which the two ends of a long portion of nerve are placed upon the cushions of two galvanometers, and the middle of the nerve is laid across the poles of a galvanic apparatus. Looking at the needles of the galvanometers before passing the galvanic current, they are seen to diverge under the action of the nerve-current; and from the direction of the divergence, it is evident that this current passes from the end to the side of the nerve. Looking at the needles while the galvanic current is passing, one needle is found to move still further from zero, the other is found to return towards zero. Let AB be the nerve; let the arrows aa' and bb' be the nerve-currents included between the cushions aa' and bb' of two galvanometers; and let the arrow PN be the current between the poles PN of the galvanic apparatus; and under this arrangement the needle of the galvanometer will recede, and show increase of cur-

Fig. 6.



rent (+) at the end B, where the nerve-current and galvanic current coincide in their direction; and at the end A, where the two currents, natural and artificial, do not coincide in their direction, the needle of the galvanometer will go back, and show decrease of nerve-current (-).

The third fact, which has been recently furnished by Professor

Eckardt, is to be found in an experiment which may be illustrated by means of the two following figures. In this experiment, the nerve of a properly prepared frog's leg is placed, one portion (that nearest to the leg) across the poles $I\ I'$ of an induction coil, another portion across the poles $P\ N$ of a galvanic apparatus. Having done this, the leg is first thrown into a state of tetanus by passing a series of induced currents, and then (the tetanizing influence still continuing in operation) the continuous current of the galvanic apparatus is transmitted from P to N . This is the experiment. The result is that the tetanus ceases when, as in fig. 7, the inverse current

Fig. 7.



passes, and continues when, as in fig. 8, the direct current passes. Nor is this result altered by inverting the order in which the con-

Fig. 8.



tinuous and induced currents are made to act upon the nerve. Thus the induced currents produce contraction if applied after the direct continuous current, but not if applied after the inverse continuous current. Nay, it would even seem as if the direct current is actually favourable to contraction; for a solution of salt, which of itself is too weak to produce tetanus when applied to a nerve, will have this effect when a direct current is made to pass through another portion of the same nerve. In performing this experiment, Professor Eckardt proceeds as follows:—First of all he tetanizes a frog's hinder limb by placing a portion of the nerve nearest to it in a strong solution of salt; after this he adds water until the strength of the saline solution is no longer sufficient to keep up a state of contraction in the muscles; then, all things being as they were, he passes the direct current through a portion of nerve which is not immersed in the solution. *The result is that the tetanus immediately returns.*

Now, on comparing this last fact with the two previous facts, we may have, as it seems to the author, some insight into the mode in which the galvanic current acts upon nerve in the period of alternate contraction. On the one hand, it is seen that tetanus is prevented or arrested by the inverse current; that is to say, tetanus is prevented or arrested when (as the first and second facts show) the galvanic current coincides in direction with, and imparts power to, the nerve-current. On the other hand, it is seen that tetanus is *not* prevented or arrested by the direct current; that is to say, tetanus is *not* prevented or arrested when (as the first and second facts still show) the galvanic current differs in direction from, and diminishes the power of, the nerve-current. The one result is in harmony with the other; for if contraction is counteracted by imparting power to the nerve-current, it is to be expected that contraction will be favoured by detracting power from the nerve-current; and certainly it is no matter of wonder that contraction should be favoured by detracting power from the nerve-current, for it is an established fact that *rigor mortis* is coincident with absolute extinction of the nerve and muscular currents, and that ordinary contraction is attended by unmistakeable *weakening* of these currents. It is also an established fact, that muscular contraction is produced by the *discharge* of ordinary statical electricity, and not by the charging and charge. Nay, it is not improbable that the contractions at the beginning and ending of the current, in the period of double contraction, which contractions have been referred by the author to the action of induced currents, may in reality be due to the *withdrawal* rather than to the *communication* of these currents; for these induced currents are of momentary duration, disappearing at the very instant of appearing, and exhibiting peculiarities in disappearing which connect the disappearance with the *discharge* of statical electricity, rather than with the more quiet cessation of current electricity.

And if this be so—if the inverse current antagonizes and the direct current favours contraction—then we may in some degree understand how it is that contraction occurs alternately at the beginning of the direct, and at the end of the inverse current.

When the *inverse current* passes, there is no contraction at the beginning of the current, for the influence of this current upon the nerve-current is one which antagonizes contraction; when the inverse

current ceases to pass there is contraction, for then the influence which antagonized contraction is removed. When, on the other hand, *the direct current* passes, there is contraction at the beginning of the current, for the influence of the current upon the nerve-current is one which favours contraction; when the direct current ceases to pass, there is no contraction, for then the influence is no longer one which favours contraction.

(c) In the third period—*that of single contraction*—the muscular movements resulting from the action of a galvanic current upon nerve are at first sight somewhat perplexing; but with a little thought, it may be seen that the same key will apply to their interpretation.

If, as has just been mentioned, contraction attends upon the beginning of the direct current because this current is found to favour contraction, it is not difficult to find a reason which will explain in some degree, not only why in *the period of double contraction* the strongest contraction is at the beginning of the direct current, but also why in the first part of the period now under consideration—*that of single contraction*—contraction should continue to attend upon the *direct* current after it has ceased to attend upon the *inverse* current. Nor are the apparent irregularities in contraction, the “voltaic alternatives,” entirely inexplicable; for it may be that these seeming irregularities—this apparent shifting of contraction from the beginning of the direct to the beginning of the inverse current, and so backwards and forwards once and again—may be nothing more than the natural consequence of the changes which at this time have taken place, and are taking place, in the direction of the nerve-current.

III. “Letter from Lord HOWARD DE WALDEN AND SEAFORD, Her Majesty’s Minister at Brussels, to Lord JOHN RUSSELL, on a recent severe Thunder-storm in Belgium.”
Communicated by the Right Hon. Lord JOHN RUSSELL.

The writer states that the thunder-storm burst between seven and eight o’clock at night on Sunday the 19th of February, and was accompanied by an unusually heavy fall of snow throughout Belgium. Twelve churches were struck almost simultaneously,